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PURIFICATION OF WATER BY THE ULTRA-VIOLET RAYS[1]

By M. von Recklinghausen, Ph.D.

It is a matter of common knowledge nowadays that the ultra-violet rays have a strong bactericidal power. Within the last few years this power of annihilating microbes by ultra-violet rays has been applied for freeing water of germs and a new industry has sprung up which produces water purifiers that make use of this new principle to sterilize water for drinking and other purposes. As this system is being applied successfully to large water plants it is of interest for the professional water engineer to be fully informed on the principles underlying this most recent system of water purification.

HISTORICAL

The treatment of water by artificial light sources for the purpose of destroying its germ life dates back to Downs and Blunt (1878). They found that the shorter the wave lengths of the light the better the bactericidal action; and they were corroborated in this later on by Duclaux, Arloing, Roux, Geissler and others. We owe to Duclaux the theory that sunlight is the most common and cheapest disinfectant known.

Marshall Ward (1892) completed these important studies by analyzing the effect of arc spectra thrown on infected agar plates; wherever they were struck by violet and particularly by ultra-violet rays they were disinfected and did not develop colonies. This English scientist sterilized Thames water by placing it in a tank equipped with a quartz window and submitting it to the rays of an arc lamp. This was proposed again later on by Lambert.

The first complete analysis of this bactericidal phenomenon of strong light sources we owe to Finsen, who in his famous light healing establishment laid the foundation of our modern knowledge of the action of light on germ life. As you will remember the practical results of this work was the introduction of the light treatment of certain diseases by the Finsen lamp. We had, however, to await the arrival of really powerful sources of ultra-violet rays before applying light practically as a bactericidal agent for the purification of water.

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[1] Paper read before the American Water Works Association Annual Convention, Philadelphia, May, 1914.

This new source of ultra-violet rays was the mercury arc lamp built out of quartz. This mercury arc owes its origin to the work of Mr. Peter Cooper Hewitt, resulting in the well known Cooper Hewitt illuminating lamps. When the ordinary glass of these lamps is replaced by quartz glass, that is to say, fused rock crystal, we obtain a container which allows the greatest amount of the ultra-violet rays produced by the mercury arc to be sent out from the lamp.

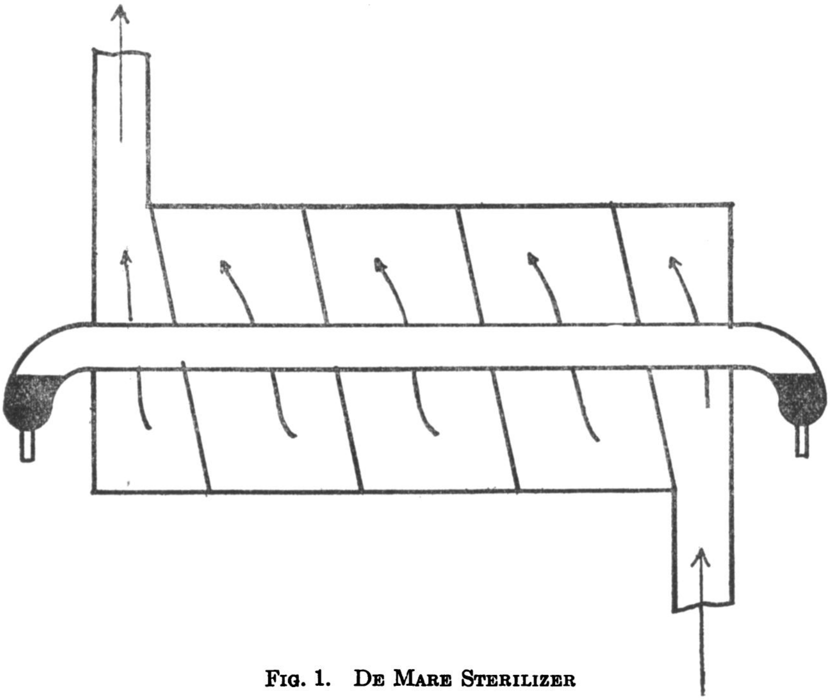

FIG. 1. DE MARE STERILIZER

The first to propose the adoption of the mercury arc for the purification of water was De Mare. His sterilizer consisted of a lamp around which the water flows in a circular path (Fig. 1). Some years later, and nearly simultaneously, different ways of constructing water sterilizers with mercury lamps were tried out by Courmont and Nogier, The Quartz Lampen-Gesellschaft, Billon Daguerre, Vallet, and chiefly by Henri, Helbronner, and von Recklinghausen. The work of the last three named was done at the Sorbonne University in Paris and was particularly elaborate in scientific research as well as practical application. This work has resulted in the installation of several large and very many small ultra-violet ray water purifiers and the writer considers it of interest to show you the development of the principles which took place during the long period of our preparatory work and the introduction of this system into actual practice.

Before going into the details of this work will mention the principle underlying the method of water purification by ultra-violet rays. We know from experiments repeated over and over again, that germs exposed directly to and at a very short distance ($\frac{1}{2}$ to 1 inch) from a powerful source of ultra-violet rays such as we use in a modern sterilizer are killed within a small fraction of a second; in some cases one-twentieth of a second being sufficient.

The principle of the ultra-violet ray water sterilizer is therefore very simple: All we have to do is to lead the water at proper speed through a zone which is illuminated by a lamp which produces a light which is very rich in ultra-violet rays. Every microbe that gets under sufficient influence of the rays during the passage of the water through this illuminated zone is annihilated. We therefore have to attend to two things: first, to an economic illumination of water with ultra-violet rays and second, to make sure that every microbe contained in the water will be really led through the illuminated zone.

If we consider the latter point first we come immediately to the conclusion that nothing must be in the water to intercept the rays, that is to say, there must not be any suspended matter in the water in the shadow of which the germ would be protected from the rays emitted by the lamp. It is therefore imperative that the water be clear. The best way to examine this is to look at the water under a strong light against a dark background. We shall later come back to this point of clearness of the water, as it is of great importance for the economy of the system.

SOURCE OF ULTRA-VIOLET LIGHT

Practically every source of light emits some invisible ultra-violet rays together with the visible rays. This can be studied by dissolving the light into its components by means of a quartz glass prism. Our human eye will see on such a spectrum only the well known colors of the rainbow. It will not see the wave lengths below the red nor the wave lengths beyond the violet; however, the latter can be easily demonstrated by certain properties they have, for example, certain dye stuffs show a fluorescent color when struck by the ultra-violet rays, also many chemical and physical reactions will take place under the influence of these ultra-violet rays and prove their presence in the spectrum thereby.

The artificial sources of light which are richest in ultra-violet rays are the electric arcs between metal electrodes, for instance, the iron arc, mercury arc, etc. All such arcing between metals is accompanied by disintegration of the metals themselves, therefore the electrodes have to be renewed from time to time. In the case of mercury this renewing can be done in the simplest and easiest manner, namely, by condensing the mercury escaping from the arc and leading the so condensed mercury back to the electrode container. Of course, the arc in this case has to be enclosed hermetically in a container so as to avoid loss of mercury. The material we choose for making this container must be such a quality that the desirable rays are not held up thereby, but on the contrary are allowed to escape freely. This material for the arc container is fused rock crystal or more properly expressed, fused quartz.

For a given amount of electrical energy, put into this arc, such a quartz arc lamp will attain a certain temperature, depending upon its radiating capacity, that is to say on its shape and surroundings. We have found that the amount of ultra-violet rays produced by such a quartz lamp is considerably more when running at a high temperature, than when it is run at a low temperature. The production of ultra-violet rays is therefore the more economical the higher the temperature of the lamp. This high temperature is obtained by raising the voltage of the lamp (fig. 4). We are, however, limited to a certain temperature, namely about 800°C., by the fact that quartz if maintained for a long time at a higher temperature will devitrify becoming thereby more or less opaque to the visible and invisible rays emitted from the arc. As in a water sterilizer we naturally want to approach the lamp as close as possible to the water, we must be careful to consider what has just been said about temperature and prevent the water from cooling the luminous part, rendering it thereby inefficient in its production of ultra-violet rays.

PHYSICAL CHARACTERISTICS OF ULTRA-VIOLET LIGHT

The ether vibrations can be distributed in four groups according to their wave lengths, namely, (1) the electric rays, (2) the infra-red rays, (3) the rays of the visible spectrum, (4) the ultra-violet rays.

Between the last electric rays and the first infra-red rays exists probably a group of still unknown qualities. All these rays travel at the same speed namely, 300,000 kilometers per second. The wave lengths are as follows:

1. Electric waves (Hertz 1888) from several kilometers down to 3 mm.
2. Infra-red rays (Herschel, 1800) from 300 down to 0.76μ.[1]
3. Visible rays (Newton, 1666) from 0.76μ down to 0.40μ.
4. Ultra-violet rays (Ritter, 1802) from 0.40μ down to 0.10μ.

We are interested today in that last named group, number 4, namely the ultra-violet rays whose upper limit is more or less vague (fig. 2). It is sometimes placed at 0.3969μ, however even shorter waves can be noticed by the eye, although not directly but only by the fact that the crystalline in our eyes becomes fluorescent giving thereby impression of gray on the retina. If people therefore have sometimes thought they were able to see ultra-violet rays they really only saw their own crystalline. The lower limit of 0.10μ of the ultra-violet rays was obtained by Schumann and Lyman by working in vacuum with fluorspar prisms. However, these very short wave lengths do not come into consideration in our case, because a few millimeters of air absorb completely the wave lengths below 0.150μ and several centimeters of air absorb the wave lengths below 0.1850μ. Several kilometers of air absorb the ultra-violet from 0.2943μ down. This wave length is therefore the shortest of the sun's waves reaching our eye,

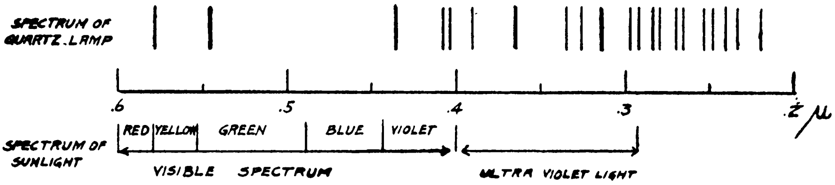

FIG. 2 SPECTRUM OF QUARTZ LAMP AND OF SUNLIGHT

and therefore the ultra-violet contained in the sun's rays are only the wave lengths between 0.40μ and 0.2943μ.

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[1] $\mu = \frac{1}{1000}$ millimeter = 10,000 Angström units.

Quartz the only material which we can apply for our lamps absorbs practically everything below 0.20μ; therefore we may say that from the ultra-violet ray efficiency point of view it does not matter very much whether a quartz lamp is surrounded by a thin layer of air or by vacuum. Glass absorbs ultra-violet rays to an enormous extent as may be seen from the fact that the bactericidal power of a quartz lamp is cut down to $\frac{1}{1000}$ if the lamp is surrounded by a glass tube.

BACTERICIDAL POWER OF ULTRA-VIOLET RAYS

It was of interest to see whether different microbes had different resistivities against ultra-violet rays in the same way that they are different against disinfectants and heat. We come to the astonishing result that they do not vary anything like as much in their resistivity against ultra-violet light as they vary in their resistivity against heat and disinfectants. For instance, spores are often twenty times as resistant as the unprotected forms of germs against chemicals. We find that some are only 1.5 to 5 times as resistant against ultra-violet light as ordinarily unprotected water bacteria. The following table (fig. 3) shows a comparison of different types of germs in their resistivity. In each case under similar conditions cultures were made and the free germs put in clear water, care being taken however to avoid clumps of bacteria and also to avoid the presence of the nourishing medium, for otherwise the germs would have been protected more or less against the rays.

It has sometimes been thought that the bactericidal action of the ultra-violet rays was due to a small amount of hydrogen peroxide which indeed forms itself by the exposure of water to the ultra-violet rays. However, this formation is so minute that it is barely noticeable after ten hours exposure of the water and we can surely say that the bactericidal effect is not due to the action of the so-formed disinfectant, but is a specific typical action of the ultra-violet rays on the germ. It is not likely that by the action of the rays during such a short period, the entire bacteria should be chemically changed, coagulated, or otherwise modified, but it is more probable that some ferment or similar product contained in the cell is modified by the rays and thereby poisons the system of the cell.

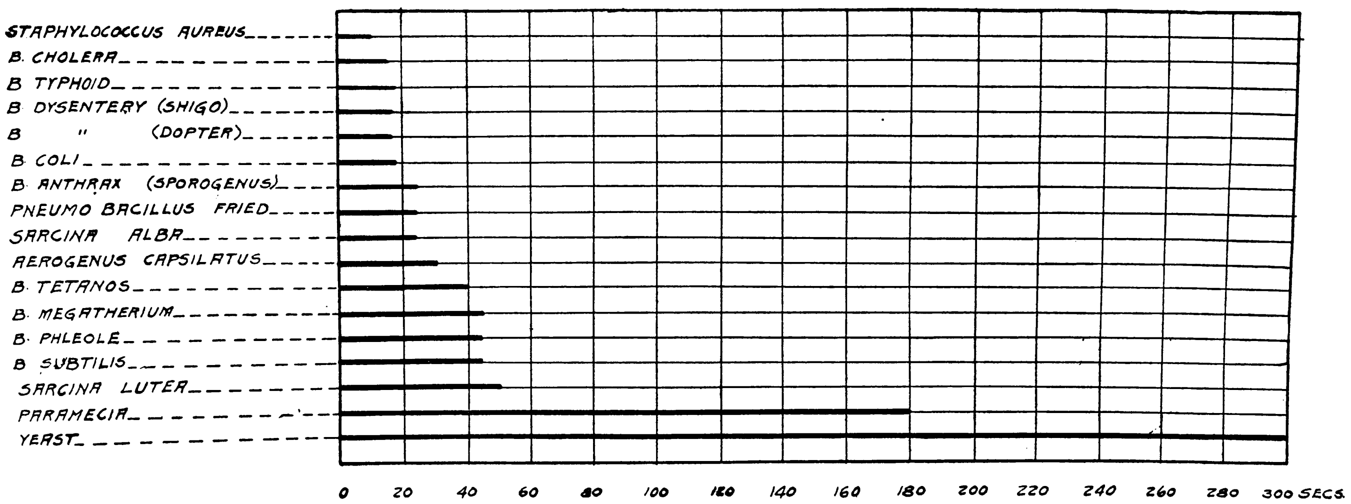

FIG. 3. SECONDS NECESSARY TO KILL DIFFERENT TYPES OF GERMS AT 200 MILLIMETERS FROM A QUARTZ LAMP BURNING AT 66 VOLTS, 3.5 AMPERES

We have often been asked whether the germs struck by the light may not be simply stunned and may survive again afterwards. In answer to this will say that the methods of making the counts in Europe would enable one to find out whether there is any reviving. These counts extended over a period of usually fifteen days and never have shown any indication of revival.

QUANTITOMETRY OF ULTRA-VIOLET RAYS

The luminous power of light sources is usually measured by comparing them with standard lamps, such standard lamps being produced by burning some well-defined fuel in a certain defined way. The moment that the light one wants to measure has a color different from the standard lamp, great difficulties arise, based on the fact that we do not really compare the two lamps physically but only physiologically.

The difficulty of determining the *ultra-violet* candle power of a lamp is far greater again, as we are not sensible to these rays at all. To get some idea of the strength of ultra-violet source we have therefore to create new means and units of comparison. Many different chemicals and physical reactions take place in the ultra-violet light. One may, therefore, base a measure of the ultra-violet candle power on the speed and strength of such a reaction. The most typical and most convenient reaction of this kind is the blackening of photographic paper. We have found that a mercury quartz lamp will blacken paper about four times as quick as the same lamp screened behind a glass plate. An ordinary sensitometer can be built embodying this principle. Another reaction of the ultra-violet rays may be considered by comparing the amount of fluorescence produced by the lamps, but both of these methods of measuring will only allow us to compare light sources of similar composition. They do not give us what is really most interesting for us, namely, a measure of the *bactericidal power* of a lamp, and we therefore thought it best to adopt a real biologic test for the measure of the abiotic strength of quartz lamps. While in the above cases we could easily determine the standard of black or the standard of fluorescence it is impossible to define in the last-mentioned case the standard of bactericidal action. There remains, therefore, nothing for us to do but to establish a standard source of ultra-violet, that is to say, a laboratory standard composed of a certain lamp which is so kept that it is most

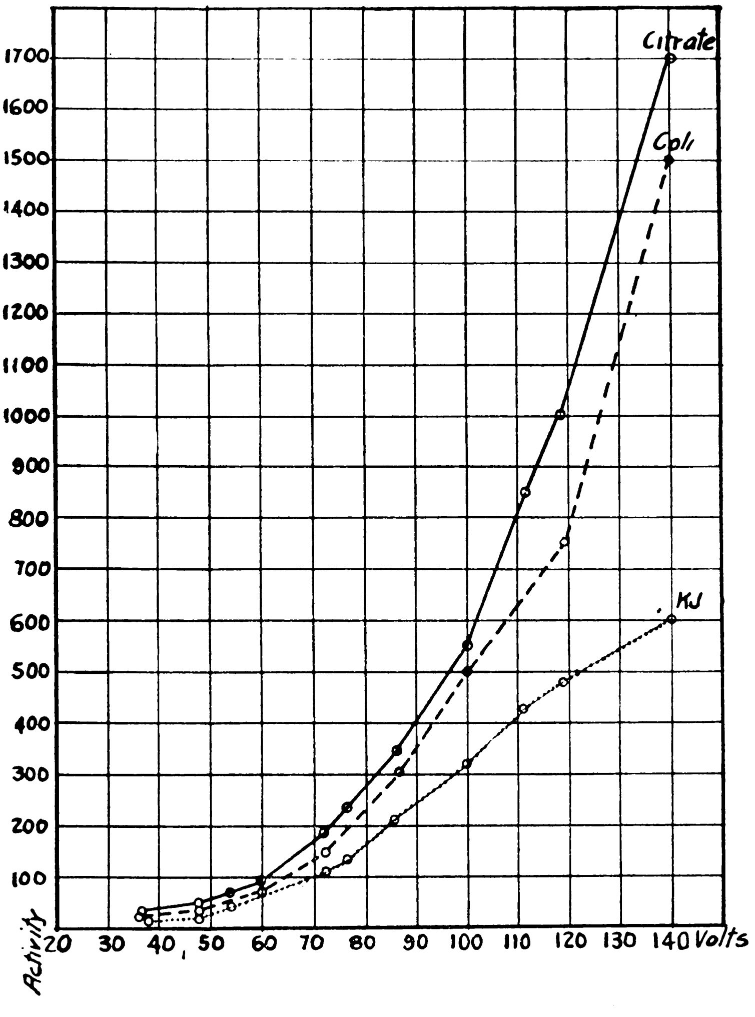

FIG. 4 COMPARATIVE MEASURE OF ULTRA-VIOLET ACTIVITY OF 220 VOLT QUARTZ LAMP BURNING AT DIFFERENT VOLTAGES BY THREE METHODS:

a. Decomposition of Citrate of Silver
b. Decomposition of Potassium Iodide
c. Anihilation of Bacterium Coli

unlikely to change the candle power and compare the action of this lamp with the action of the lamp one wants to measure on one and the same culture of germs. The way we proceed for this process is as follows: we make a culture of paramecias which are very similar in their sensitivity to ultra-violet rays as ordinary water bacteria. As a matter of fact they will stand about six times the exposure that bacterium coli will stand as figure 3 shows.

The sensitivity of such a culture is determined by exposing a drop of it at a defined distance from the laboratory standard quartz lamp. Another drop of it is exposed at the same distance to the lamp one wants to measure and the time necessary for killing gives the indication of the relative value of ultra-violet candle power. We have chosen paramecias because they are easily observed under a microscope, having a rather violent motion while alive and naturally no motion when dead.

A few observations will therefore give us within a few minutes a definite idea of the bactericidal power one wants to measure.

We may say that we have checked figures so obtained with the effect on coli cultures and can see thereby that we have a fairly safe process for determining by comparison, the ultra-violet candle power of a lamp. We have used it particularly to determine the power of lamps which had been in service for longer or shorter periods.

With all that we may say that the action on photographic papers is, in most cases, a precise enough indication of the ultra-violet candle power, as may be seen from figure 4.

It is natural that the electric characteristics of the lamps for these measures are checked up by the usual electrical instruments indicating the amperage and voltage of the lamp.

DEVELOPMENT OF THE STERILIZING APPARATUS

The experiments we made at the Sorbonne laboratory as well as the experiments of others working in this field were started by exposing polluted water in containers to the light of the quartz lamps. These experiments allowed us to get data for the construction of sterilizing apparatus where the water was circulating continually through the illuminated zone.

As examples, for the simplest form of apparatus, will mention the sterilizing tank which we used in our preliminary experiments (fig. 5), and Nogier (fig. 6) and the Quartz lampen Gesellschaft (fig. 7). In all of these experiments the water was simply passed in a straight flow underneath or around the source of the ultra-violet light. We found the results with this type of apparatus to be irregular and came to the conclusion that this was due to the fact that the water, although clear, still contained some microscopic suspended matter

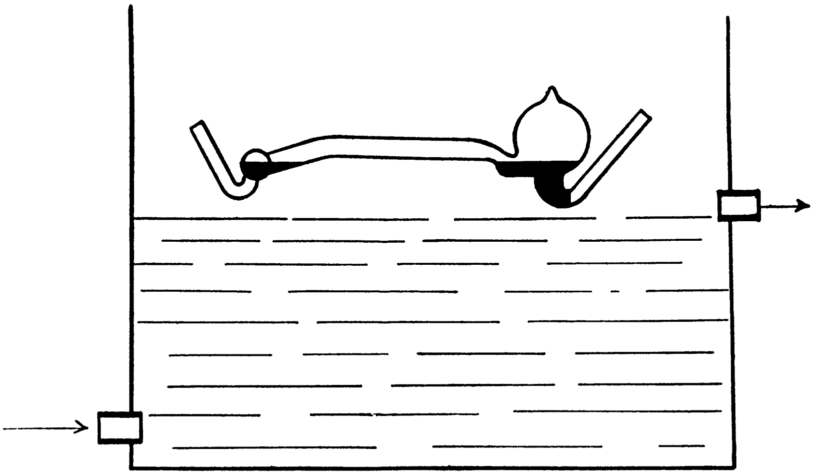

FIG. 5

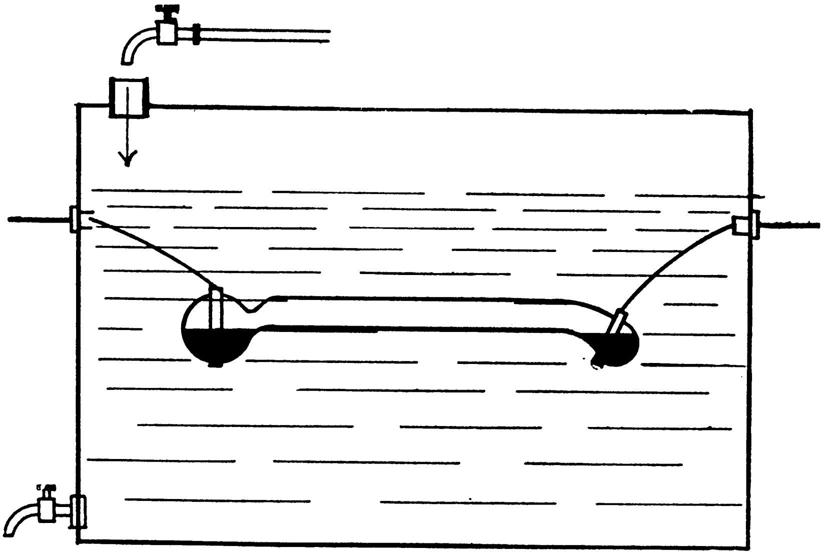

FIG. 6

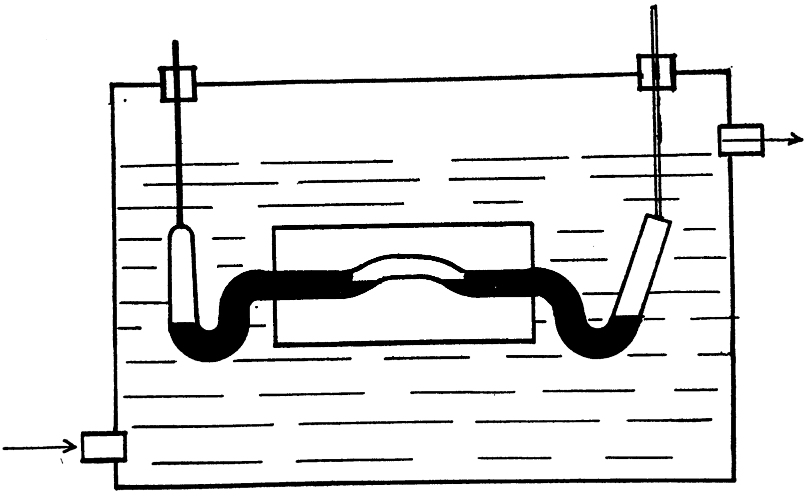

FIG. 7

which when the water was flowing straight would allow microbes to be shielded.

We, therefore, considered it advantageous to expose the water a second and third time to the light after having stirred it between illuminations. In this way we expected to turn over such microscopic particles and have them therefore exposed on all sides to the action of the lamps. A typical case of such apparatus was used by us in experiments at the Sorbonne and is shown in the design figures 8 and 9. The water in a similar apparatus of considerably larger size (fig. 10) flowed through four illuminated zones and stirred itself up through its flow around the bends of the canal between the luminous zones. The results were very satisfactory as we obtained sterilization from about 5000 germs per cubic centimeter down to less than 10 per cubic centimeter, the consumption of electric energy for the lamps being at the rate of 144 kw. hours per million gallons. The submitting of the water to successive illuminations and stirring up during illumination can also be done with a single lamp by so arranging baffles that the water is led several times towards and away from the source of the light (figs. 8 and 9). Typical apparatus of this kind is shown in the B2 (fig. 11) and C3 (fig. 12) apparatus. The former apparatus, B2 type, uses only perhaps one-fourth of the light emitted by the lamp. However the apparatus is easy to handle and of a small size.

The C3 apparatus was constructed in a somewhat different way,

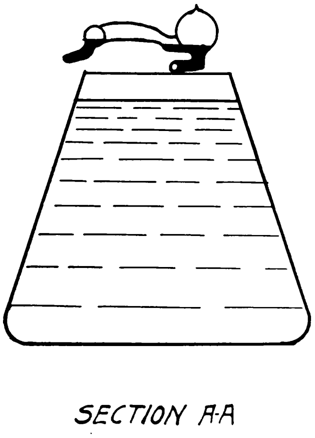

Fig. 8

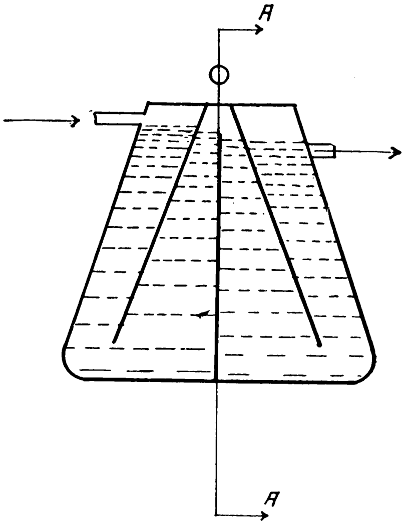

Fig. 9

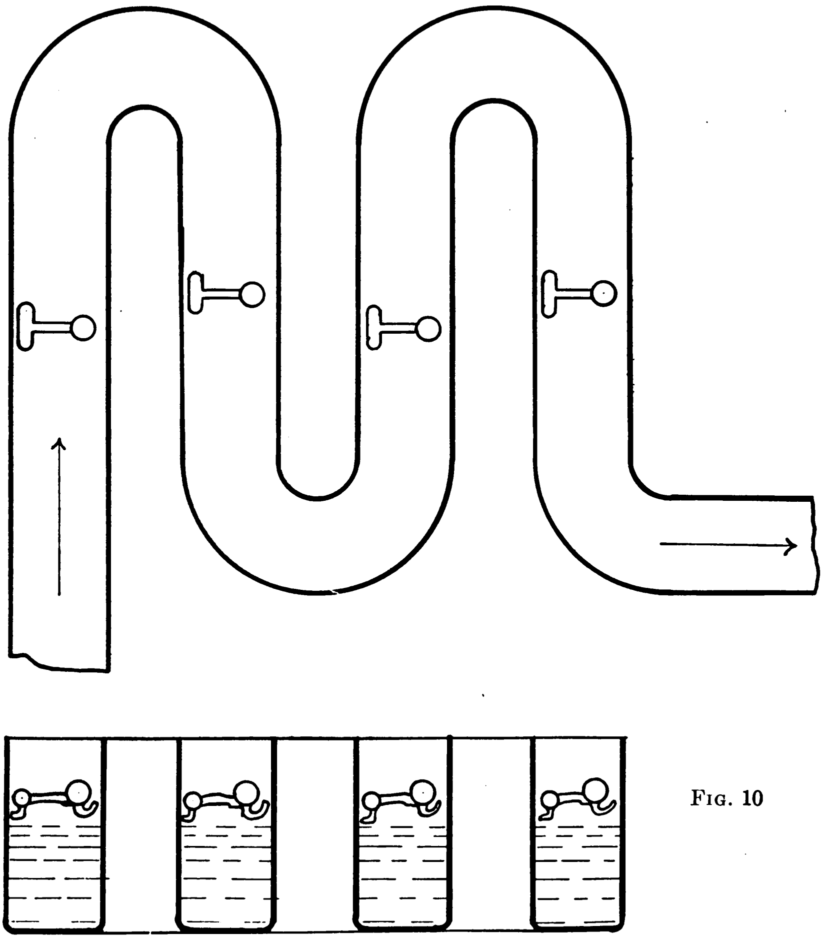

Fig. 10

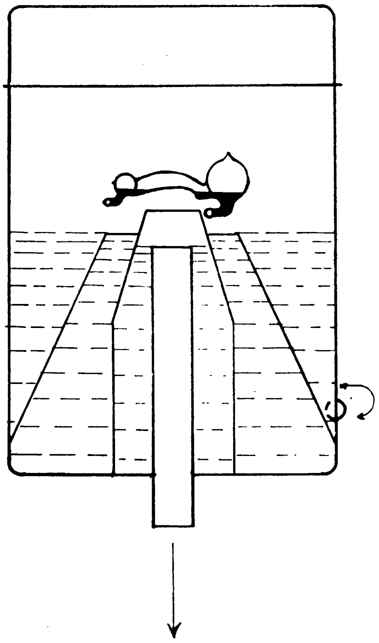

Fig. 11

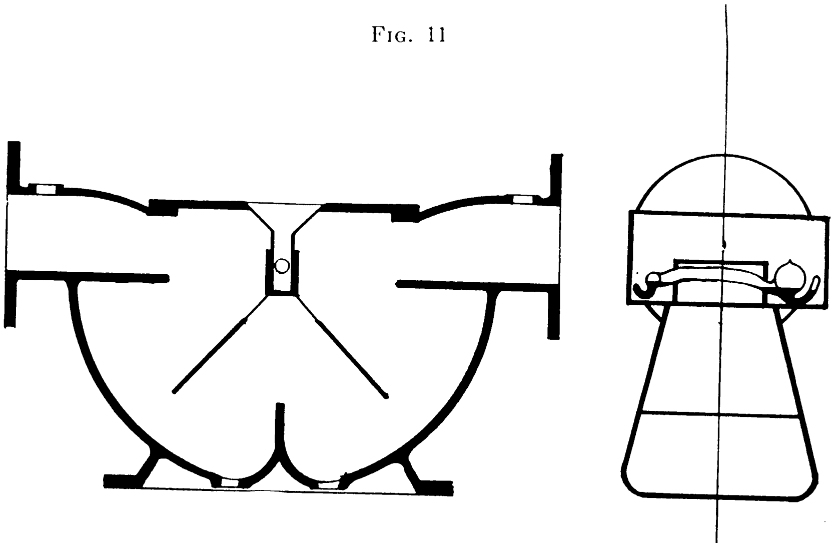

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Fig. 12

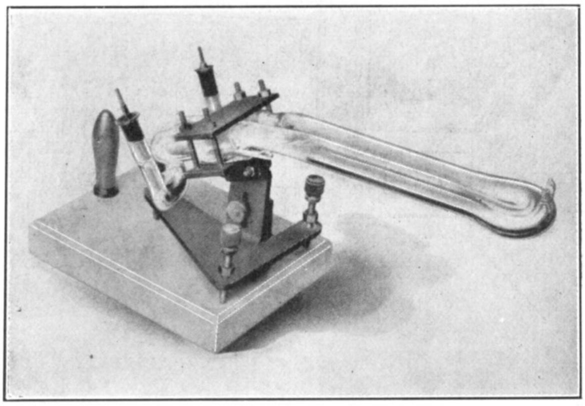

FIG. 13

with a view of using a greater proportion of ultra-violet. The lamp was protected from contact with the water by inserting it into a chamber fitted with quartz windows which chamber was submerged in the tank containing the water. Three contacts of the water with the light are obtained in this apparatus.

It was desired to so construct the lamps that practically all their light could enter into the water and exert its sterilizing action. The so-called pistol lamps which have a U-shaped luminous tube (fig. 13) allow this to be realized, the luminous part being inserted into quartz tubes which protect them from contact with the water (figs. 14 and 15). Such pistol lamp equipments can be inserted into flumes through which the water flows and give the water several successive illuminations (figs. 14, 15). The necessary stirring action in the water is obtained by baffle plates placed in the lamp axis whereby fairly violent stirring is taking place near the lamp.

The largest lamp unit made so far is the 500 volt 2.5 amperes, pistol lamp and a maximum number of ten such lamps are inserted into one single flume.

As to the depth of water in sterilizing apparatus, theoretically the best will be a very great depth of the water. We have observed strong bactericidal action even through three feet of water, the ratio being practically as may be expected inversely as the square of the distance, that is to say for instance, one-ninth of bactericidal action at three times the distance. Calculation and practice have shown us that it is good to provide, if possible, 2 feet depth of water in

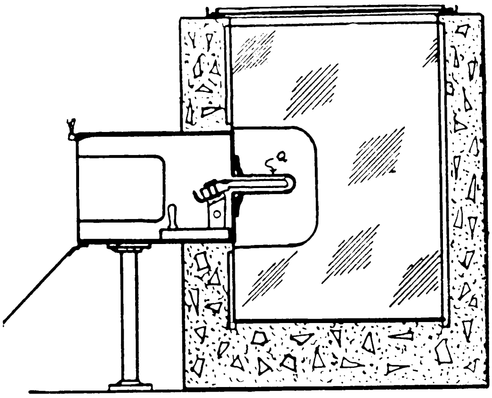

FIG. 14

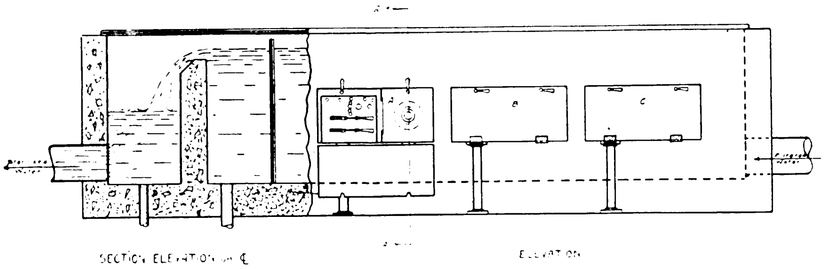

FIG. 15

larger apparatus. Of course in apparatus working with water which is highly colored, this depth may be reduced as otherwise it would make the apparatus unnecessarily cumbersome.

INSTALLATIONS

The whole system having been developed abroad it is only natural that there are considerably more such installations in Europe than in this country. Small installations are used for producing water for drinking and surgical purposes in hospitals, schools, etc., also for bottling purposes. The first large installation of a C3 apparatus (rate of 150,000 gallons per day) has been running since November, 1910, in a suburb of Rouen. The hygienic results from this plant are very satisfactory, typhoid in the district fed with the water from

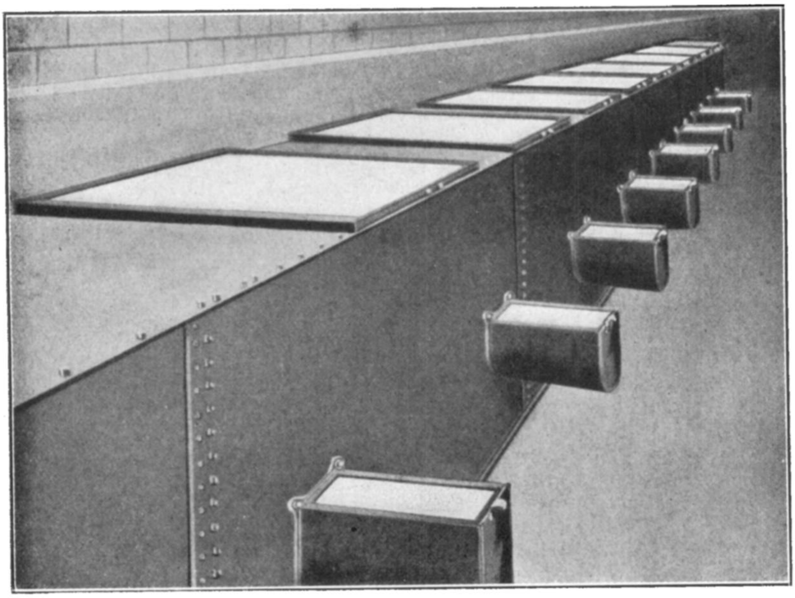

FIG. 16

this plant being extinct whilst it exists still in the surrounding districts which use similar water without ultra-violet ray purification.

A plant with four 220-volt pistol lamps has been running for over a year in Saint Malo sterilizing the water at a rate of 750,000 gallons per twenty-four hours.

Many C3 apparatus are running in France in some cases two being run in series with always very gratifying results. The largest sterilizing unit composed of a flume with ten 500-volt pistol lamps is sterilizing the water for the city of Luneville, France (fig. 16). This supply consists of 1,500,000 gallons of river water and 375,000 gallons of spring water. The water in this case, which in its raw state is extremely muddy and rich in colloidal matter, is filtered through a rough and slow sand filter without the addition of coagulants, at a rate of about 7,000,000 gallons per acre. In case of a biological filtration this type of water would have to be filtered at the rate of 2,500,000 gallons per acre.

The raw water contains countless germs like any heavily polluted river. After filtration it contains at times as many as 1000 germs per cubic centimeter. The water leaves the sterilizer with rarely more than 10 germs per cubic centimeter, and no coli bacteria, although the water before sterilizing nearly always shows positive coli reaction. Even more gratifying is the hygienic result as may be seen from the following statistics of typhoid mortality in this city; showing the number of cases:

Year	*Jan.* *Feb.* *Mar.*	*Apr.* *May* *June*	*July* *Aug.* *Sept.*	*Oct.* *Nov.* *Dec.*
1908	15	6	121	20
1909	57	12	7	55
1910	19	3	5	46
1911	69	5	32	10
1912	14	11	9*	2
1913	2	5	3	5
1914	0			

*** Start of Ultra-Violet Ray Plant**

On account of some turbidity, and also an often deep color of the filtered water (up to 40 U. S. standard) this plant has an exceedingly high current consumption, namely, 130 kw. hours per million gallons; during most of the time two-thirds of this consumption would be ample.

The first application of the ultra-violet ray system for sterilizing water on a large scale in this country was started some weeks ago in New York, where the water of a swimming pool is continually being circulated through a rapid filter and a sterilizer flume, equipped with two 220-volt pistol lamps, the flow being about 5000 gallons an hour.

PRELIMINARY CONDITION OF THE WATER BEFORE TREATMENT WITH THE ULTRA-VIOLET RAYS

As mentioned in the theoretical part the ultra-violet rays must be able to strike the microbe; where any suspended matter is interposed the bactericidal action cannot take place, because the microbe is in the shadow. It is certain therefore that only clear water can be submitted to the ultra-violet ray treatment for its sterilization. That is to say in most cases it is necessary to filter the water before the same is submitted to the action of the lamps. As color in solution will absorb ultra-violet rays to a certain extent, it is evidently better to also free the water from coloring material before submitting it to the rays. Nevertheless we have treated water like the above mentioned Luneville waters showing up to about 40 U. S. standard in color. It is certain in such cases more illumination is necessary than with water having no coloring matter in solution.

The question of suspended matter, in the water, is of somewhat greater importance. Sometimes water with little suspended matter may be more difficult to sterilize than water with far more suspended matter. The reason for this is that it will depend not only on the size and quantity of the suspended matter but also on its biological quality. That is to say suspensions of purely mineral nature which do not enclose any microbes and to which few microbes are attached handicap the sterilization of the water very much less than suspended particles in similar water which are heavily covered with microbes and particularly so if microbes are enclosed in these particles, because it is then most likely that a repeated exposure to the rays will be necessary to penetrate to the enclosed germ life.

If the suspended matter is of smaller size than the germs like colloidal clay we expect such turbidity to act more or less like color in solution, demanding simply more illumination than clear water. Experiments made with one of the B2 apparatus on water showing up to 20 turbidity seem to prove that such fine turbidity does not handicap sterilization very much.

From the economical point of view the condition in which the water is submitted to the rays is evidently of great importance for the ultra-violet rays sterilization system. Physically ideal water, that is to say, water without suspended matter, turbidity or color will need very little power in ultra-violet ray to become sterile. In large plants 50 kw. hours per million gallons will produce a great *over-dose* in ultra-violet and it will always be more economical to adopt the filtering system which gives the physically best results because it will also be the most economical in its demand of ultra-violet ray treatment.

Smaller installations are being equipped usually with charcoal or paper filters. In large plants naturally the filter question is an engineering proposition; so is the question of choice between mechanical and sand filter.

It seems that if the latter are chosen they can be speeded up to a great extent as against the speed for biological filtration and still give a physically pure enough water for ultra-violet ray treatment, as for example the Luneville plant where the water is filtered practically at three times the rate of biological filtration for that particular kind of water. In other plants the filtration has been speeded up to 10,000,000 gallons, to 12,000,000 gallons per acre and we even tried with fair success 25,000,000 gallons per acre followed by ultra-violet ray treatment. This will naturally always depend on the filtrability of the water.

OPERATING COSTS

Operating costs will vary with the size and the running hours of the plant, and the *coefficient of safety* one wants to give to the ultra-violet ray treatment. According to the quality of the water, in large plants the current consumption will vary between 50 and 125 kw. hours per million gallons allowing for a large safety coefficient. The labor charges are negligible as the apparatus only needs an occasional cleaning and starting of lamps. Apart from this the lamps have to be repumped and repaired from time to time. When the water is of variable physical quality, one will have so to establish the plant that all the lamps will be running during the period of least transparent water and only some of them during the period of best transparency.

In any engineering proposition we always try to adopt as large a *safety coefficient* as possible. It we rely merely on chemicals to disinfect our water, we must work right close to and sometimes even over the limit of the amount which will not make itself objectionable by producing taste and odor in the water.

There is an increasing opposition to the use of chemicals for the purification of water supplies except as a makeshift as we may see from the remarks made by Mr. George A. Johnson, in the *Journal of the American Public Health Association,* (Aug., 1911) where he mentions the great difficulty of avoiding under-dosing or over-dosing. Mr. Allen Hazen speaks even of the "Difficulty or sometimes the impossibility of disinfecting waters with hypochlorite of lime without at the same time producing disagreeable tastes .or odors."

In the ultra-violet rays we have a system where we may choose *our safety coefficient as high as ever we liked,* that is to say, we may *over-dose* our sterilization as much as we want without creating any objectionable features in the water, like taste and odor. The waterworks engineer has therefore in this system a much more satisfactory weapon against pollution than he ever had before.

DISCUSSION

Mr. F. A. Dallyn: The Association is to be congratulated upon obtaining this paper from Dr. von Recklinghausen. He has been very modest indeed in his claims for the ultra-violet rays. He has certainly given us a most scientific paper upon the working of the system. In the experimental station attached to the provincial board of health, Ontario, a very small unit, type B2, has been tested. The speaker is very much of the opinion that we have just had the first word upon the ultra-violet ray for water sterilization (using the word "sterilization" advisedly) and that we will hear more of it as time goes on. The cost appears to be only about three times that arising out of the use of ordinary disinfecting agents. No doubt, public opinion will demand its use just as soon as its merits are clearly before the minds of the people.

Mr. Sheppard T. Powell: Some time ago the speaker did some work with ultra-violet rays, employing the apparatus which Dr. von Recklinghausen has described in his paper, figure 11, namely, the small domestic sterilizer. We got it about two and a half years ago direct from London. In this work we used Baltimore city water. This was before we had sterilization by hypochlorite of lime.

Before applying this method the total bacterial count ran from a few hundred to several thousand, but by the use of the sterilizer, although the time of contact was very short, we found almost absolute sterility of the water resulted. The main thing that the speaker thinks this Association should consider in ultra-violet ray sterilization is the question of cost. Dr. von Recklinghausen reports an average K. W. consumption of 30 to 125. Now if we place that average at say 75, and put the cost at 2 cents per K. W.; which most of you will agree is low enough except in a hydro-electric proposition, we have a K. W. consumption cost alone of $1.50. To this must be added the depreciation and interest on investment which will make a very considerable cost, especially when you consider that this is merely for the sterilization of the water exclusive of filtration. It is not so much the question of the efficiency of the ultra-violet ray as a bacteriacidal agent as it is the question of what it is going to cost. Of course the liquid chlorine method is becoming more and more popular, so that these lamps will have to be very much reduced in cost and something done to bring them into such condition that they will not have to be re-pumped so often, before the ultra-violet rays will be a practical method of water purification.

Mr. B. F. Shaw: The speaker was interested in the statement in the paper of the success attained at Luneville with water containing a rather high amount of color. Several years ago he did a small amount of work with the mercury arc lamp, working with Boston tap water which had a moderate amount of color, about 4 U. S. Standard. He found that the absorption appeared to be practically complete even in so short a distance as 20 cm. There appeared to be no bacteriacidal effect at that distance with water of that color, and would like to ask if Dr. von Recklinghausen will state whether the results obtained in measuring the effect of the lamp on the bacterial culture, by means of the time taken to kill the bacteria present, are consistent in a number of cases using the same source of light and the same culture? The speaker never attempted anything of that character himself, but the work that has been published by Professor Phelps of Boston and Mr. Chick of England, and others, on the character of curve of disinfection, and its resemblance to the logarithmic curve, would seem to indicate a priori that the time of disinfection would be a quantity difficult to determine closely, and rather unsatisfactory as a measure of the ability of the lamp to disinfect.

Dr. Max von Recklinghausen: The first question asked was in reference to the cost. Mr. Powell is quite right that the cost is somewhat higher than the mere use of chemicals, especially when one considers that the lamps will need repairs and repumping after a certain time. The speaker has often had that experience with lamps used in the laboratory, and not in continuous service. They suffered much more than lamps which are started once by the operator and are then left burning for days and months. If the lamps are handled frequently as is the case in testing in the laboratory they will suffer infinitely more than when in continuous, regular and quiet service. There is no doubt that a laboratory lamp needs perhaps, ten times as much repairing as a lamp which is put in service in a plant and left burning. The depreciation of lamps is evidently a cost factor but do not think that it should run very high. Of course, the speaker does not want to give any commercial figures but he knows that the lamp makers themselves are willing to stand back of the lamps.

Now let us say that the ultra-violet ray treatment does cost more than the treatment with hypochlorite or treatment with chlorine, is there not a great advantage in the possibility of *overdosing* a sterilizing agent to an enormous extent without having any secondary reaction going along with it, that is to say without producing *bad* water? What are we after? We want to produce good water. Good water should evidently taste good too, and should always taste good. If we use chemicals we may be able to often keep below the limit of taste and odor and get practically sterile water but is it not better to *over-do* the sterilization to a great extent and be sure that you never get *any* taste. This matter really ought not to be measured upon the basis of dollars and cents alone.

On the other hand, handling chemicals such as hypochlorite and particularly liquid chlorine is not only disagreeable but even dangerous. There is no doubt about that, and you have to protect your operators against injuries from these chemicals.

Another thing mentioned when speaking about the relative resistivities of different types of germs is that the spores are not very much more resistant against ultra-violet than ordinary water bacteria. This is very important as some spores are pathogenic. Contrary to chemicals the ultra-violet rays act practically as well on spores as they do on ordinary water bacteria, and, therefore, sterilizing the water with ultra-violet rays creates a much *safer water*, and the slogan here in this country is always "safety first."

As to the results mentioned when exposing Boston tap water of the color 4, the speaker believes that these experiments were made without observing all necessary precautions; though of course, he can not trace this particular case in detail, he has been able to trace most cases of irregular results down to the presence of a certain amount of suspended matter. He personally has never worked with Boston water. Of course, it may be beautifully filtered at the water works but whether it gets in the same condition to the tap, he does not know. So that in the tests there might have been some growth introduced from the inside of the pipes into the water which was being tested, which protected some of the germs contained in the water from the action of the lamp.

Some years' experience with the ultra-violet rays have given the speaker the feeling of having an absolutely safe sterilizing agent. There is nothing mysterious about them, and if one follows the rule of taking water without suspended matter of any kind one will always get the same regular sterilizing results. We have often found a total absence of bacteria in 40 cc. even when working with water having up to 40 U. S. standard color. Therefore the tests on Boston tap water with only 4 in color must have been made under unfavorable conditions.

As to the consistency of the figures on relative resistivity of different germs you are referred to our original publications. To repeat these tests needs very careful work so as to prepare the germ cultures in such a way that they will be as near as possible in a similar physical state. The germs must not be in clumps, but isolated. They must not be imbedded in their medium of culture, but floating freely in the water. If one compares for instance broth cultures directly one will get very uneven results, because the bacteria may be in clumps and besides protected against the light by the colloidal contents of the broth.